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AN ORGANIZED EFFORT TO DEVELOP THE HYDROTHERMAL ENERGY RESOURCE

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ABSTRACT

As a response to America's need for Alternate Energy sources, the U.S. Department of Energy has a Geothermal Program. Within this program is a Hydrothermal category. Currently, a wide range of tasks are being addressed as part of the Hydrothermal Program. The tasks include Industrialization, Reservoir Technology, Hard Rock Penetration and Conversion Technology. It is thought that successes already made in this program combined with upcoming successes will increase the likelihood of geothermal energy becoming a contributor to our nations future energy needs.

INTRODUCTION

During the 1970's America became increasingly concerned about its dependence on imported fossil energy. As a result, a push was made to locate alternate energy resources. Among the many alternative resources being considered was Geothermal energy. There were, and are, several characteristics about the Geothermal Energy resource which make it advantageous over other resources. It's abundance in the United States and the fact that it poses a minimum hazard to the environment are among the many advantages. However, there were many unknowns concerning this resource. Therefore, the United States Department of Energy (USDOE) increased its' effort in their Geothermal Program. This effort continues today.

Because of the various forms in which the Geothermal resource takes, the USDOE's Geothermal Program consists of four categories: Hydrothermal, Geopressured, Hot Dry Rock and Magma. The intent of this paper is to describe the Hydrothermal category and give a present status of its' projects.

The hydrothermal resource consist of large reservoirs of heated fluid. The temperatures of these reservoirs vary which in turn varies the way they are utilized. Low and moderate temperature resources, (10 to 150 °C) are used primarily in direct used applications such as heat pumps aquaculture, and space heating. High temperature resources, (>150 °C) are more commonly used for power generation.

There are many challenges to utilizing the hydrothermal resource. These challenges include locating and quantifying the resource, drilling into the resource, handling the brines, answering power plant development and maintenance questions, and injecting the brines. The goal of the Hydrothermal Program is to provide solutions to challenges such as these. By providing solutions to these challenges and others like them, the ultimate goal of reducing the life-cycle cost of electricity produced from the hydrothermal resource at 3 - 10 cents / kWh by 1992 can be achieved.

Because of the wide range of utilization and the accompanying challenges, the Hydrothermal Program has been divided into four tasks. These tasks are Industrialization, Reservoir Technology, Hard Rock Penetration and Conversion Technology. DOE-HQ located in Washington D.C. provides the program management for all of these tasks. The project management for all of the tasks in the Hydrothermal Program with the exception of the Hard Rock Penetration task is provided by DOE-ID located in Idaho Falls, ID. The project management for the Hard Rock Penetration task is provided by Sandia National Laboratory, located in Albuquerque, NM. The fiscal year 1989 funding levels for these tasks is shown in Table 1. It should be noted that since fiscal year 1989 funding for industrialization was $0, prior year funding was used to carry out the task.

<table>
<thead>
<tr>
<th>Task</th>
<th>Funding, ($K)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reservoir Technology</td>
<td>2,900</td>
</tr>
<tr>
<td>Hard Rock Penetration</td>
<td>2,400</td>
</tr>
<tr>
<td>Energy Conversion</td>
<td>2,030</td>
</tr>
<tr>
<td>Industrialization</td>
<td>0</td>
</tr>
</tbody>
</table>

TABLE 1 - FY-1989 FUNDING FOR TASKS IN HYDROTHERMAL PROGRAM

Each task consists of several projects. These projects are being carried out by various government labs, universities and contractors. A description and status of the four tasks and their respective projects will now be presented.
INDUSTRIALIZATION

The goal of the industrialization task is to promote the use of Geothermal Energy throughout the nation and the world. The industrialization task is broken up into two projects. These projects are State-Coupled Grants and Direct Heat Participation & Support.

State-Coupled Grants - The State-Coupled Grants project consists of 12 cost shared grants to various groups to study aspects of geothermal energy that are not being studied by private industry, but which have the potential for results that will be applicable to industry. The total funding for the grants in this project is $1,319,800. The grant participants and a brief description of their projects follows.

The University of Alaska, Geophysical Institute is performing a geologic and geochemical study of the Geyser Bight geothermal resource, the hottest (180-264 C) and most extensive area of thermal springs in Alaska.

The state of Alaska, Division of Geological and Geophysical Survey in cooperation with the University of Alaska is completing a fluid chemistry investigation and geological map of the Geyser Bight KGRA. In addition, a geothermal energy resource map of the Aleutian Islands is being prepared.

The state of Hawaii, Department of Business and Economic Development is studying methods to control silica deposition from geothermal fluids of the Hawaii East Rift Zone.

The state of Idaho, Department of Water Resources is studying and monitoring three geothermal systems: the Banbury resource, Boise geothermal aquifer and the Wood River geothermal system.

The Desert Research Institute, University of Nevada System is conducting detailed hydrologic monitoring of the Moana geothermal system.

The University of Nevada Las Vegas, Division of Earth Sciences is integrating fluid geochemistry, stable light isotope data, glacial ice data and archaeological information to study the genesis of geothermal fluids in the Great Basin.

The New Mexico Research and Development Institute is conducting an evaluation of time-integrated radon soil-gas surveys in the southern Rio Grande Rift.

The state of North Dakota, Mining and Mineral Research Institute is bringing together the North Dakota and South Dakota Geological Surveys and UND staff for a comprehensive geothermal resource assessment of these two states.

The state of Utah, Geological and Mineral Survey is conducting a geothermal resource assessment at the New Castle geothermal area.

The state of Washington, Department of Natural Resources has drilled eight 150 meter temperature gradient holes to improve the southern Washington Cascade range heat flow data.

The state of Washington, State Energy Office is finalizing a computer program (GEODIM) which optimizes the design of wells, pipes, pumps and heat transfer systems.

The University of Wyoming, Department of Geology and Geophysics is developing an improved three-dimensional computational scheme for solving the combined heat conduction and forced convection equations for determining subsurface temperatures.

The majority of these grants will be completed by October, 1989. If additional funding becomes available for this project, it will be continued with new grants being issued.

Direct Heat Participation & Support - The Direct Heat Participation and Support project is made up of activities which have been or are taking place under three grants. The three grantees are the Oregon Institute of Technology, Geothermal Resource Council and the National Geothermal Association.

The grant with the Oregon Institute of Technology is to perform research and development assistance in areas of geothermal direct-use development, and moderate temperature (90 - 150 C) wellhead electric generating systems. The assistance, which is available at no charge, is generally limited to 8 hours. The Oregon Institute of Technology is also involved in doing research and development on issues which pertain to the geothermal direct use arena. This work results in documents such as the Geothermal Direct Use Engineering and Design Guidebook which will be available to the public in April 1989.

During the past two years, the Geothermal Resource Council has held a grant to promote the international sales of U.S. geothermal equipment. To do this the GRC held a conference in September 1987. Twenty-three participants were present from 18 countries. Over the past year, follow up information has been obtained and a final report summarizing the conclusions of the conference was delivered to DOE in January 1989. Included in this report is a response by the conference attendees indicating that the U.S. geothermal technologies most needed by foreign countries are binary cycle power plant technology and cooling system technology. The final report is available for interested persons.

Currently, a grant is being put in place between the DOE and the National Geothermal Association which will promote U.S. Power Plant technology and U.S. Drilling and completion technology. The activities associated with this grant will consist of meetings between interested foreign developers and U.S. Power Plant and Drilling
Industry Representatives. The intent of these meetings will be to promote sales of U.S. Geothermal Technology in these areas. A final report will be provided to the DOE in September 1989. This report will also be available to the interested persons.

RESERVOIR TECHNOLOGY

The goal for the Reservoir Technology task is to improve the technology for geothermal energy resource utilization by developing and testing analytical and interpretive methods to more effectively locate, develop and utilize hydrothermal resources. By obtaining this goal, it is thought that:

Industry will be enabled to maximize energy recovery from a resource through more realistic predictions of reservoir performance.

The adverse thermal and chemical effects of injection on geothermal reservoirs will be reduced.

New techniques to identify fractures in geothermal reservoirs and to locate geothermal reservoirs will be verified.

The task is broken into four projects: Reservoir Analysis, Exploration Technology, Brine Injection, Geothermal Technology Organization.

Reservoir Analysis - The Reservoir Analysis project is intended to provide analytical and interpretive tools for determining reservoir characteristics and reservoir performance with greater certainty. The objectives for the project are to improve production well siting and decrease the uncertainty associated with long-term reservoir decline. Several activities are currently taking place in this project.

The Lawrence Berkeley Laboratory (LBL) and the University of Utah Research Institute (UURI) are developing new geophysical equipment and field testing its’ use for monitoring fluid flow in reservoirs. They are also continuing the testing of vertical seismic profiling and microseismic monitoring for detection and mapping of fractures in geothermal systems. Finally, they are developing and verifying computer Dbased methods to evaluate the use of borehole geophysical techniques for locating fractures and permeable zones in geothermal systems.

Stanford University, the Idaho National Engineering Laboratory (INEL) and LBL are analyzing field data from individual production well tests and interference tests. They will refine computer modeling techniques for identifying reservoir processes and evaluating their impact on the response of hydrothermal systems to development. In addition, UURI, LBL and INEL are interpreting field data and attempting a synthesis of knowledge about reservoir processes.

Stanford and LBL are continuing their efforts to develop theoretical and computer models to predict reservoir performance from combined well testing and production history. They are using laboratory physical models to develop techniques for simulating the response of geothermal systems to different reservoir management programs and evaluating the usefulness of these techniques for estimating the generating capacity and longevity of these systems.

Brine Injection Technology - The Brine Injection Technology project addresses industry needs for effective and environmentally acceptable injection systems which reduce adverse impacts on geothermal reservoirs. The objective for this project is to decrease the uncertainty associated with injecting brines into producing reservoirs. The project is focusing on three specific areas: fluid migration, fluid-rock chemical interactions, and injection well placement.

UURI is evaluating potential geothermal tracers in laboratory experiments simulating natural geothermal systems. They will develop, with industry, field operations techniques for tracer injection, sampling, and interpretation to track the transport of injected fluid. INEL and Stanford are applying computer modeling techniques to the tracer return field data for the determination of reservoir physical properties and fluid interactions in the reservoir. UURI, Stanford LBL and INEL are participating in a field test with Oxbow Geothermal Company in the Dixie Valley system to verify tracer usefulness and to develop interpretative methods to analyze tracer results.

LBL and UURI are performing theoretical studies of geophysical techniques to determine if injection of spent geothermal fluids can generate signals which can be detected at the surface with existing geophysical equipment. They will design equipment capable of detecting the theoretically determined signals if existing equipment is found to be unsuitable.

INEL is continuing to develop computer models with the capability to analyze and predict the flow of injected fluids through reservoirs. INEL researchers are investigating the potential for coupling the fluid flow computer model with models of chemical interactions between rocks and the injected fluid. The INEL fluid flow model FRACSL is available for simulation of injection into commercial geothermal systems.

Exploration Technology - The Exploration Technology project is designed to develop techniques to locate and characterize geothermal resources. The objectives for this project are to increase the success ratio of wildcat wells and to devise better methods of discovering hidden geothermal systems. The following work is currently being done in this project.
UURI is collecting and analyzing existing data from geothermal exploration projects and is integrating it with geological, geophysical and geochemical data from field and laboratory investigations to develop conceptual models for exploration of geothermal systems. UURI is also utilizing this data to prepare case studies of resource exploration for the industry.

UURI and LBL are performing numerical analysis to determine theoretical geophysical responses from fluid filled fractures and are designing and conducting field tests of surface geophysical techniques to verify the responses expected. They are investigating the use of new interpretation methods for locating fractured hydrothermal systems. They are concentrating on electromagnetic and passive seismic methods of exploration and will combine the observed geophysical data with laboratory measurement of physical properties and existing geologic data to provide exploration plans for regions like the Cascades volcanic province for which the data sets are available.

**Geothermal Technology Organization**

The Geothermal Technology Organization (GTO) has been formed by the DOE and Industry to sponsor geothermal technological development. The geothermal industry works with the DOE through a cooperative research agreement between the DOE Idaho Operation Office and the GTO. The DOE is represented in the GTO by the INEL.

Research selected for funding by GTO has a high likelihood of yielding near term benefits.

**HARD ROCK PENETRATION**

The goal of the Hard Rock Penetration task is to reduce the cost of drilling in hostile environments where the geothermal resource is most commonly located. The task is broken into four projects: Lost Circulation Control, Rock Penetration Mechanics, Instrumentation and the Geothermal Drilling Organization. All of the projects in this task are being carried out at the Sandia National Laboratory.

**Lost Circulation Control**

Lost Circulation is seen by industry as a significant expense in drilling geothermal wells. The objective for the Lost Circulation Control Project is to reduce costs associated with lost circulation episodes. Currently, research is being directed toward developing techniques for characterizing and controlling lost circulation in geothermal drilling. There are three primary areas of activity that are currently being pursued.

Development of techniques for detecting and characterizing loss zones in order to determine which control techniques should be employed in a given circumstances.

Development or identification of suitable high temperature bridging materials for loss zones characterized by a porous matrix or minor fractures.

Development of new techniques for plugging loss zones characterized by large fractures or vugular/cavernous zones.

The majority of work to date has been directed toward the development of bridging materials. This is based on the need for materials that will successfully plug minor loss zones so that more drastic measures such as cement plugs are not necessary. Recent lost circulation material testing and theoretical modeling indicate that easily measured mechanical properties such as compressive strength, elastic modulus and softening temperature control the fracture plugging capabilities of potential lost circulation materials.

**Rock Penetration Mechanics**

Recovering core economically from deep, hot environments such as those where geothermal resources often are is very difficult. In addition, the current bottomhole tools and assemblies must be improved to reduce deviations and improve drilling rates. Therefore, the objective for the Rock Penetration Mechanics project is to reduce deep coring costs and to reduce costs of deep wells and directionally drilled wells.

Currently, research in the Rock Penetration Mechanics project is directed toward manufacturing insulated drill pipe, studying advanced hard rock drilling and coring systems and building transmitting and receiving transducers for acoustical data telemetry systems. In general a basic description of rock penetration by candidate innovative drilling/coring systems is being derived. Over ten years of work spent determining the behavior of polycrystalline diamond compact drag bits in relation to rock fracture and wear mechanisms is being summarized. Other research areas include development of high temperature drilling systems for operation above 300 C, and advanced concepts for drilling or coring in hard rock. Additional work is directed at collecting real time drilling and formation data from a transducer located on the bit. A data transmission scheme using acoustical carrier waves within the drill string appears promising for improving data rates by 50 fold over commercial mud pulse telemetry.

**Instrumentation**

Instrumentation used to locate resources and to measure parameters at great depths is often inaccurate. The objective for the Instrumentation project is to increase well siting accuracy at a reduced cost and decrease the uncertainties which accompany down hole measurements.

Electronic memory tools for pressure and temperature measurement to 400 C have been built and successfully used at temperatures to 350 C.
well depths up to 17,000 feet and for extended periods in lower temperature wells. The current R & D effort in the instrumentation project includes two activities. First, a downhole scanning radar operating in the frequency range of 30 to 100 MHz is being developed to locate fracture zones in geothermal resources, and second electronic memory tools are being developed for downhole measurements in wells where the temperature limit of wireline cable is exceeded.

Geothermal Drilling Organization - The Geothermal Drilling Organization is a nonprofit organization between members of industry and the DOE to cooperatively fund projects in the drilling arena. The objective for this project is to develop and transfer drilling technology which will result in additional cost reductions to industry.

The development efforts of the Geothermal Drilling Organization include projects selected by industry for short term payoff. Current, development includes a high temperature acoustic borehole televiewer for fracture identification in open holes and for casing inspection in cased wells; a polyurethane foam tool to control lost circulation problems in zones of high permeability; a pneumatic turbine for directional drilling; high temperature drill pipe protectors; and high temperature elastomers for rotary head seals.

ENERGY CONVERSION

The goal for the Energy Conversion Task is to develop concepts which will allow better utilization of Geothermal energy at a reduced cost. The Task is broken into three projects: Heat Cycle Research, Materials Development and Advanced Brine Chemistry.

Heat Cycle Research - It has been indicated in several recent studies that geothermal developers are very concerned with power plant technology. In particular, developers have expressed an interest in binary plant technology and cooling systems. The Heat Cycle Research Project is primarily concerned with advancing power plant technology. The objectives for the project are as follows:

- Increase net geothermal fluid effectiveness of binary plants
- Increase net geothermal fluid effectiveness of conventional binary plants through the utilization of supersaturated vapor expansions in the turbine
- Reduce heat rejection system cooling water make-up requirements for geothermal power plants, while retaining performance comparable with conventional wet cooling.

The Heat Cycle project is carried out by the Idaho National Engineering Laboratory, (INEL). The project utilizes a Heat Cycle Research Facility to generate experimental power plant data. This facility is a small (640 kW) power plant located in East Mesa, CA. Data received from this facility is taken to the INEL for analysis.

Since the spring of 1988, the project has been relocating the Heat Cycle Research Facility to GEO's East Mesa McCabe site. The relocation will be completed by May 1989 and testing will resume at that time. The testing to be done in the near future is summarized below.

It is known that if the condenser pressure can be decreased, the efficiency of a binary power plant can be increased. Therefore, the project is examining methods to decrease this pressure. Currently, three methods are being evaluated: countercurrent flow, enhance surface characteristics and integral mixing during condensation. Testing will be completed on this work by October 1989 and evaluation of the data should be completed shortly after.

Supersaturated turbine expansions theoretically can be done to increase net geofluid effectiveness. However, this is not done due to concern for extensive wear to turbine blades if liquid droplets form. The INEL has developed a 2-D nozzle which will be used to determine the limits regarding supersaturated turbine expansion and blade wear. Testing for this activity will begin in the August 1989.

In addition to the Heat Cycle Research Facility activities, work is also being done to evaluate more advanced cycles and to test materials which may result in heat exchanger scale reduction.

Material Development - Geothermal brine is often extremely difficult to work with. It's high temperature and corrosiveness make the selection of materials to use for drilling a well, producing a well, and operating a geothermal power plant very difficult. The objective for the Material Development project is to reduce the costs associated with lost circulation, develop well cementing materials which have a lifetime of 30 years at 400 - 600 °C and develop corrosion resistant, low fouling heat exchangers. This project is currently broken into four activities described below. All these activities are being conducted out of Brookhaven National Laboratory, (BNL).

The development of advance high temperature cements is being conducted in three phases. First, light weight cements are being tested in low CO2 containing brines. The testing will be completed prior to October 1989. Second, ceramic-like cements which can be used for well completions at temperatures up to 500 °C are being
developed. Third, CO₂-resistant high temperature cements are being developed.

A thermally conductive polymer concrete coating has been developed at BNL. This coating is being tested in a heat exchanger apparatus which was built and will be tested by the Idaho National Engineering Laboratory in Hawaii. The results of this experiment will be analyzed and reported in a collaborative effort by both laboratories.

Advanced elastomers for downhole drill motors are currently being developed. These elastomers are being optimized for sealing applications and for use as a stator in a downhole drill motor. To date the work has been focused on developing and doing laboratory tests. If these tests are successful, the elastomers will be fabricated and field tested.

Chemical systems for lost circulation control are currently being developed at BNL in a collaborative effort with Sandia National Laboratory's Hard Rock Penetration Task. Efforts at BNL consist of developing chemical systems which are tested at the Sandia National Laboratory. If the current tests are successful, the chemical systems will be tested in the field.

Advanced Brine Chemistry - Handling and disposing geothermal brine can be difficult. This is often due to the brine chemistry. Brine scaling results in handling difficulties. Brine chemical content often results in disposal problems which arise for environmental reasons. The advanced brine chemistry project is attempting to reduce these obstacles. The project consists of two activities: modeling and waste disposal.

The modeling activities are taking place at the University of California at San Diego, (UCSD). The objective for this activity is to reduce the costs associated with scale deposition on production well casing and power plant equipment. UCSD is carrying out research involving aqueous chemical models for geothermal process design. The University has developed a variable temperature model which accurately calculates solubilities in the sodium, calcium, chloride, sulfate and water systems from 0 to 250 °C and from dilute to high ionic strength. Current modeling activities are focussing on the addition of model parameters for hydrogen sulfide solubility, plus the incorporation of bisulfate species.

The waste disposal activities are taking place at Brookhaven National Laboratory, (BNL). The objective for this activity is to reduce costs of surface disposal of sludge from geothermal brines. In cooperation with industry, BNL is developing low-cost biochemical processes to concentrate and remove toxic materials from geothermal brine residues. Three types of bioreactors have been constructed. Tests are now being carried out to reduce residence times and to compare the overall efficiency of the three bioreactor designs.

CONCLUSION

It is evident that in the Hydrothermal program, a significant amount of work is being done on a large range of subjects. This work is being done to solve the problems which may inhibit industry from developing the hydrothermal resource. In order for this work to be effective, industry must provide the government with input regarding their specific concerns. This is currently being done in many of the projects, however more industry input and involvement is always needed.

With continued research in the Hydrothermal program, it is hoped that the ultimate objective of reducing the cost of electricity produced from the hydrothermal resource will be achieved. If this takes place, it will be a positive step in our country's search for alternate energy sources. More importantly, it will allow our nation to reduce its' need for foreign energy products.

ACKNOWLEDGMENT

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REFERENCES


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